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Improving the Performance of Asphalt Mixtures Using Nano Silica

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Abstract- Black-top asphalts face challenges, particularly cracking and rutting. These issues arise within the asphalts due to deficiencies in mix properties and increasing traffic loads. They occur as a result of insufficient black-top coverage and blend quality. This paper focuses on enhancing the qualities of black-top mixes using Nano Silica (NS). The research involves analyzing the properties of modified mixes with NS at concentrations of 3%, 5%, 7%, 9%, and 11% by weight of bitumen. Marshall tests, retained Marshall tests, Indirect Tensile Strength (ITS) tests, as well as penetration and softening point tests are used to evaluate the properties obtained. Results indicate that the optimal NS content is 7% by weight of bitumen. Modifying the black-top mix with 7% NS increases the Marshall strength by 32.42%, decreases penetration by 7.93%, and raises the softening point by 10.34%, while maintaining similar unit weight and keeping air voids and other mix properties within acceptable limits. Overall, the addition of NS successfully enhances the characteristics of black-top mixes.

Keywords- Nano Silica, Sotening Point, Stability, percentage passing,NS,Marshall

I. INTRODUCTION

Asphalt surfaces experience several issues, such as rutting, fatigue, and moisture damage throughout their lifespan. These failures reduce the pavement's functionality and require frequent maintenance, leading to increased overall life-cycle costs. Researchers have been working on developing additives, such as polymers and elastomers, to enhance the performance of asphalt under varying climatic and load conditions.

Nanomaterials are defined as "materials with any external dimension at the nanoscale or having internal structure or surface structure at the nanoscale," with the nanoscale defined as "ranging from 1 nm to 100 nm." This category includes both discrete nano-objects and nanostructured materials that possess internal or surface features at the nanoscale.

Objectives of the Present Investigation

- The objective of the current study is to study the impact of nanomaterial additiveon the properties of bituminous mixtures.
- To evaluate the asphalts pavement modified by nanosilica and improving theperformanceof asphalt pavement by using fillers as nanosilica over VG30.

II. LITERATURE REVIEW

From the past researchers ,google scholar, different websites following literature review can be done from the present study:

Yusoff et al.(2014) This study investigated the performance characteristics of polymer-modified asphalt (PMA) blended with nano-silica particles. The polymer-modified asphalt, PG-76, was mixed with nano-silica at concentrations of 0%, 2%, and 4% by weight of the asphalt binder. Various tests, including moisture susceptibility, dynamic modulus, and dynamic shear rheology, were conducted to assess the performance of the PMA with nano-silica under different aging and moisture susceptibility conditions. During the mixing process, the binders were heated to 160 °C and mixed at a shear rate of 1500 rpm for approximately one hour.

Microstructural analyses of the asphalt binders were performed using scanning electron microscopy (SEM). The SEM images revealed that the nano-silica particles were well dispersed within the asphalt binder matrix. The addition of nano-silica reduced the susceptibility to moisture damage and increased the strength of the asphalt blends. Furthermore, it was observed that both fatigue resistance and rutting resistance were enhanced in the PMA blended with nano-silica particles. Aging index values indicated that the susceptibility to oxidative aging significantly decreased with the incorporation of nano-silica, particularly under long-term aging conditions. The addition of 4% nano-silica to the PMA showed the greatest potential for beneficial modification of the binder.

Shafabakhsh et al. (2015) Nanotechnology has gained widespread application in recent years due to its unique properties that enhance various materials, including asphalt binders. Hot mix asphalt (HMA) has a long history as a cost-effective paving material. However, as viscoelastic materials, HMA blends can fail in different ways when subjected to varying temperature profiles and loading stresses over time. In HMA pavements, three common types of distress are observed: rutting, fatigue cracking, and thermal cracking. These issues lead to poor service conditions and reduced lifespan.

Rutting is particularly significant in asphalt pavements, especially in high-temperature regions where flexibility becomes a critical concern affecting performance. The consequences of rutting include premature deterioration and high rehabilitation costs. To enhance the properties of asphalt blends, steel slag has been selected for its favorable physical characteristics.

This research aims to analyze the effects of laboratory tests conducted on modified steel slag asphalt blends (SSAM) containing TiO2 and Nano SiO2 particles, which are added to improve rutting resistance in nano-modified asphalt blends. Various tests on asphalt binder properties, including penetration grade, softening point, ductility, rotational viscosity (RV), and dynamic shear rheology (DSR), were conducted to examine the rheological characteristics of the modified bitumen. Additionally, the Marshall Test was utilized to determine the optimal bitumen content in both conventional and modified asphalt blends. To evaluate resistance to rutting and fatigue life, two tests—Rehashed Load Axial (RLA) test and Fatigue Test—were performed on the asphalt mixtures containing steel slag.

Test results indicated that the inclusion of Nano TiO2 and Nano SiO2 improved the rheological properties of the bitumen, increasing durability and viscosity by an average of 30% and 109%, respectively, while reducing penetration grade. Furthermore, the rutting resistance and fatigue life of the asphalt were significantly enhanced.

Saltan et al. (2017). The aim of this assessment was to evaluate the performance of Hot Mix Asphalt (HMA) and bitumen by incorporating nano materials, as outlined by the Superpave mix design methodology. In this study, bitumen was modified with silica nano powder (SiO2NP) at concentrations of 0.1%, 0.3%, and 0.5% by weight. The rutting and fatigue performance of the modified bitumens were analyzed. HMA was prepared using the optimized binder content (OBC) with the nano-modified bitumen. The moisture susceptibility of the modified HMA was assessed using the Modified Lottman test.

The nano-modified bitumens were also evaluated using scanning electron microscopy (SEM) to determine the uniformity of the modification. The results indicated improved performance with SiO2NP at a concentration of 0.3%. The performance grades (PG) of each modified bitumen were found to be PG 64-22. The OBCs were reduced with the modification. The HMA mixture modified with 0.3% SiO2NP demonstrated a 26.25% greater resistance to moisture compared to the reference test. SEM results confirmed a homogeneous mix, with the aggregation of nanomaterials generally measuring less than 4 micrometers in the mixtures. Therefore, SiO2NP at 0.3% concentration yielded promising results.

Shi et al. (2023) In this study, the rheological properties of sixteen asphalt samples with varying concentrations of nano-silica and Qingchuan rock asphalt were analyzed using univariate and variance analysis. The experimental tests conducted included rotational viscosity (RV), dynamic shear rheometer (DSR), bending beam rheometer (BBR), and scanning electron microscope (SEM) evaluations. The RV test results indicated that both materials significantly affected the rotational viscosity, with the modified asphalt exhibiting better resistance to deformation at high temperatures.

DSR test results showed that Qingchuan rock asphalt had a notable impact on the complex shear modulus (G*) and phase angle, while the effects of nano-silica were relatively minor, mainly improving G* with minimal impact on the phase angle. BBR test results revealed that the low-temperature performance of the modified asphalt deteriorated as the concentration of additives increased, although the effects of nano-silica were comparatively small.

To achieve comparable high-temperature characteristics, the modified asphalt demonstrated less decline in low-temperature performance compared to Qingchuan rock asphalt. Moreover, relying solely on nano-silica to enhance the rutting resistance of asphalt was not deemed cost-effective.

Khadrah et al. (2024) In recent studies, nanotechnology has gradually been integrated into the field of asphalt modification. The impressive effects of nanomaterials have been harnessed to enhance asphalt performance. Researchers have conducted numerous successful experiments to develop modified asphalt, demonstrating the mechanisms of modification and the resulting performance improvements. This review first introduces various nanomaterials used for asphalt modification, followed by the methods employed to incorporate these materials, and finally discusses their effects on the properties of base asphalt along with the mechanisms of alteration.

Based on current research findings, the influence of formulation process parameters on the compatibility of each component in the modified asphalt and the stability of the modified system are also outlined. The review concludes with predictions regarding future trends in this field.

In their experiments, the researchers tested nano-silica at three concentrations: 2%, 4%, and 6% by weight of asphalt binder, mixing it into the asphalt at high temperatures to ensure even distribution. The asphalt binder was characterized using various tests, including AASHTO consistency viscosity, penetration, softening point, flash point, and Marshall Test.

The results showed that the addition of nano-silica increased the viscosity at all tested concentrations. Specifically, the penetration decreased with increasing nano-silica content, while the softening point increased proportionately. The flash point remained unaffected. In the Marshall Test, adding 2% nano-silica improved stabilization, but the stabilization value at 4% was lower than at 2% and did not reach the original sample's level. Adding 6% of the nano-silica further impacted the properties, but specific results were not detailed.

III. METHODOLOGY AND FLOW CHART

1. Flow Diagram

The figure below outlines the detailed workflow for the current research project. The study began with a literature review of relevant sources, identifying gaps that informed the objectives of the research.

Once the gaps and objectives were established, the necessary materials were sourced from the local market, and tests were conducted according to IRC standards to evaluate their suitability for the research.

Various tests were performed on aggregates, including impact value, crushing value, elongation, flakiness, and Los Angeles abrasion. For bitumen, softening point and penetration value tests were conducted. Nano silica was sourced from Hyderabad, and its physical properties were provided by the supplier.

After completing basic tests on the materials, tests on traditional bituminous mixes were conducted to determine the optimum bitumen content, as well as Indirect Tensile Strength (ITS) tests for comparison with modified bituminous mixes.

Modified bituminous mixes were prepared using the modified aggregates with different percentages of nano silica (as a percentage by weight of the optimum bitumen content) and were then tested for Marshall Stability, flow, and ITS to compare with the standard bituminous mix.

Fig- 1 Flow diagram for the present investigation

Table 1 size aggregates specific gravity value mm

Determination	Sample
Wt.OfpynometerW1(gm)	714
Wt.ofpynometer+sample W2(gm)	1284
Wt.ofpynometer+sample +waterW3	1970
Wt.ofpynometer+waterW 4(gm)	1600
Specific gravity= (W2- W1)/[(W2- W1)+(W4- W3)]	2.76

Table.2 size aggregates specific gravity value mm

Determination	Sample
Wt.OfpynometerW1(gm)	714
Wt.ofpynometer+sample W2(gm)	1136
Wt.ofpynometer+sample +waterW3(gm)	1870
Wt.ofpynometer+water W4(gm)	1600
Specific gravity=(W2- W1)/[(W2-W1)+(W4- W3)]	2.77

Table3 size aggregates crushing value 20mm

Determination	Sample
Wt.PassingISsieve12. 5mmbutretainedon 10 mm W1(gm)	3404
Wt.RetainedonISsiev e2.36afterimpact W2(gm)	2627
Wt.PassingonISsieve 2.36afterimpact W3(gm)	771
Crushing value (%)(W3/W1)*100	22.6

Table 4 Aggregates crushing value 10 mm

Determination	Sample
Wt.PassingISsieve12.5mm butretainedon 10 mm W1(gm)	3400
Wt.RetainedonISsieve2.36 afterimpact W2(gm)	2672
Wt.PassingonISsieve2.36afterimpact W3(gm)	722
Crushing value(%)(W3/W1)*100	21.2

Table3 and 4 shows the data aggregates crushing value for 20mm and 10mm size of aggregates in which the results found for 20mm and 10mm size of aggregates are 22.6% and 21.2% that is less than the maximum permissible limits given by IS 2386 part 4 which is less than 30%.

Table-5 Aggregate simple value

Determination	Sample (20mm)	Sample (10mm)
Wt. Passing ISsieve12.5mmbut retained on 10 mm W1(gm)	685	635
Wt.RetainedonISsieve2.36after 1impact W2(gm)	640	598
Wt.PassingonISsieve2.36afterimpactW3(gm)	42	35
Impact value(%)(W3/W1)*100	6.1	5.5

Table 5 shows the data aggregates crushing valuefor20mmand10mmsizeofaggregates in which results found for 20mm and 10mm size of aggregates are 22.6% and 21.2% that is less than the maximum permissible limits given by IS 2386 PART 4 which is less than30%.

Table 6 shows Los Angeles Abrasion Test value results data for 20mmsize ofaggregatestaken2500gmpassing through IS Sieve size 20mm and retained on 12.5mm and 2500gm passing through 12.5mm and retained on 10mm.And using 11 ball for 20mmsize of aggregates and 8 for 10mmsize and got the value 13.9 and 16.2percent for 20mm and 10mm aggregates which is less than the permissible limit set by IS 2386 Part 4. Permissible limits value for pavement is maximum 30%.

Table 6 Los Angeles Abrasion test

Sieve size		Wt. taken(gm)	No. Of ball	Fraction	Passing	Abrasion	Remarks
Passing(mm)	Retained(mm)	A		Retained On IS SIEVE1.7	(Gm) B	Value (B/A)*100	
20	12.5	2500	11	4286	695	13.9	MAX.=30%
12.5	10	2500					
10	6.3	2500	8	4026	812	16.2	MAX.=30%
6.3	4.75	2500					

Table-7 (a) penetration test for vg30

Reading	trails
%Air void	3-5
%VMA minimum	14
%VFB	65-75
Minimum stability(KN)	9
Number of blow	75oneachface
Penetration Value	Avg. of sample =63

Table 7(a) shows the penetration test value at 5 different point and taken penetration value as anaverageof5 point andgotthevalue63mmwhich lies between the limits set byIS73:2006.According to IS73:2006 Penetration at 25 is 50-70 for VG30.

Table4.7 (b) softening point value for vg30

Temperature When The Ball Touches Bottom	1	2
	60	56
Softening Value	Avg.OfTwo58>47	

Table 4.7(b) shows softening point value for VG30.And results found to be 58 which is greater than 47 as per IS 73:2006.

Table-8 penetration value at 7% NS

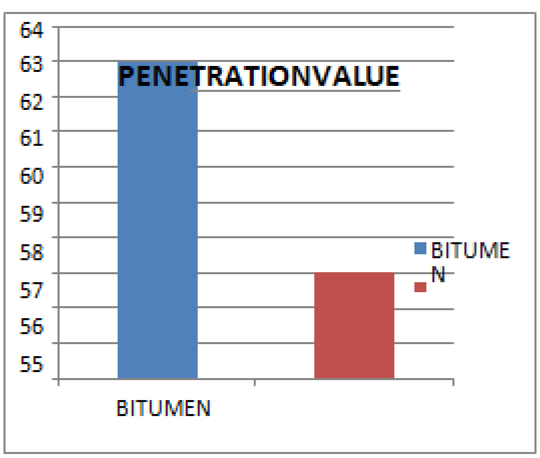
Reading	No. of trails (NSAT7%)				
	1	2	3	4	5
Initial reading A	0	68	0	66	10
Final reading B	58	128	56	122	62
Difference Value	58	60	56	56	52

Table-9 Softening Value at 7%NS

Temperature When The Ball Touches Bottom	Sample	
	1	2
Softening value	64	64
	Softening value	

Table 4.8 and 4.9 shows the penetration value and the softening value of 7% NS modified Bituminous Mix at OBC. And result found to be57as penetration value and 64°Cas softening point value.

IV. RESULT & DISCUSSION



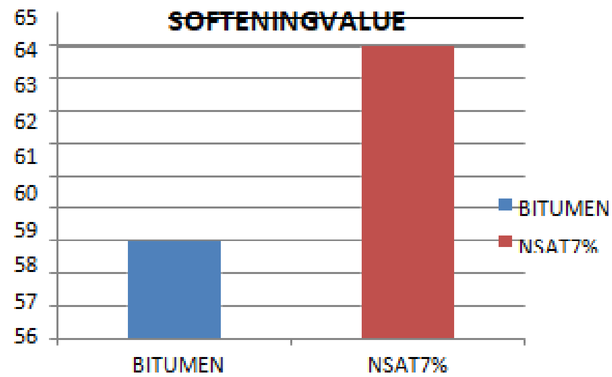


Figure 1: Penetration value and softening value between control miandnsat7%

In the Graph 1 shows that mixing NS with bitumen improves the penetration and softening properties. The penetration value decreases 6.3mm to 5.7mm by 9.52%. Softening value increases 58 to 64 which represents 10.34% increment. This is happening because of mixing of NS with VG30 as it increases the stiffness properties of Modified Bituminous Mix by increasing their bond strength between the aggregate.

V. CONCLUSION

In this study nano material were used to modify the bituminous mixes of grade-II. Nano silica was adopted for modified the bituminous mix and various mechanical properties like Marshall Stability, Flow, Retained Stability were calculated. Based on the laboratory investigation following conclusions were made for present investigation

- Optimum Bitumen Content found at5.62%ofbitumencontent.
- While adding NS to a asphalt binder, It improves the physical properties of the binder by decreasing the penetration value and increasing the softening point value of the asphalt binder. Maximum stability occurred at 7% NS added to the asphalt binder and stability value is 30.42% greater than unmodified asphalt binder. Optimum NS content is 7%.
- Maximum density occurredat5% NS added to the asphalt binder and density value is slightly greater than unmodified asphalt binder.
- Retainedstabilityfoundtobe82%.

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